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LETTERS PATENT

FOR

ULTRA-DEEPWATER TENDON SYSTEMS

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CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application Serial No. 60/401,064, filed August 5, 2002, which application is incorporated herein by reference.

BACKGROUND OF THE DISCLOSURE

The present invention relates to mooring systems for offshore floating platforms.

Offshore floating platforms, such as Tension Leg Platforms (TLPs), are held in place in the ocean by means of vertical mooring elements called tendons, which are typically fabricated from high strength, high quality steel tubulars, and include articulated connections on the top and bottom (tendon connectors) that reduce bending moments and stresses in the tendon system. Many factors must be taken into account during the design of the tendon system to keep the floating platform safely in place including: (a) limitation of stresses developed in the tendons during extreme storms and while the platform system is operating in damaged conditions; (b) avoidance of any slackening of tendons and subsequent snap loading of tendons as wave troughs and crests pass the platform hull; (c) allowance for fatigue damage which occurs as a result of the stress cycles in the tendons system throughout its service life; and (d) vibrations in the platform system arising from vortex-induced vibrations.

As water depth increases beyond about 4,000 ft, the platform system cost begins to be dominated by the cost of the tendon system due to the length and wall thickness of tendons and by fatigue considerations. To limit the amount of fatigue damage caused by each wave cycle, it is necessary to limit the vertical natural resonance periods of the platform system (heave, pitch and roll)

to the 3-4 second range for a steel tendon by increasing the cross-sectional area of the tendon (ie, by stiffening the "spring" since the "mass" of the platform is set mainly by operational considerations). The increasing requirement for more steel cross-sectional area causes the tendon system to become heavier, thus reducing the payload carrying capacity of the platform system, i.e. more and more platform buoyancy is 'consumed' merely supporting its own mooring system. This combination of increasing tendon length and tendon wall thickness causes the tendon system to dominate total installed cost of the entire platform system in ultra-deepwater.

It is therefore an object of the present invention to provide a tendon system including tendon groups comprising multiple steel tendons and one or more tendons of synthetic materials for increasing vertical stiffness of each tendon group.

It is another object of the present invention to provide a tendon system including tendon groups comprising multiple steel tendons incorporating an inner tendon(s) of synthetic materials co-axially located within the steel tendon(s).

It is yet another object of the present invention to provide a tendon system including an active control system or passive damping system that exerts damping forces on the platform through supplementary synthetic tendon(s) connecting the platform to the seabed.

It is still another object of the present invention to provide a tendon system including a passive damping mechanism that can disrupt vertical resonance in the platform system by means of tuned oscillator(s).

It is yet another object of the present invention to provide a tendon system including an active damping system on the platform that can disrupt vertical resonance in the platform system by means of a driven mass-spring oscillator(s).

SUMMARY OF THE INVENTION

In accordance with the present invention, a tendon system for anchoring a floating platform to the seabed comprises one or more tendon groups including one or more steel tendons in combination with synthetic tendons, such as carbon fiber composite (CFC) tendons. In one aspect of the invention, the synthetic tendons are coaxially located within the steel tendons.

In another aspect of the invention platform system resonance is attenuated by exerting a damping force through means connecting a computer controlled winch or hydraulic system on the platform to the seabed.

In another aspect of the invention, one tendon on each corner of the platform system is equipped with passive damping means to disrupt resonance in the platform system.

In another aspect of the invention, passive tuned oscillator(s) or active driven oscillator(s) are provided to disrupt resonance of the platform system.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above recited features, advantages and objects of the present invention are attained can be understood in detail, a more particular description of the invention briefly summarized above, may be had by reference to the embodiments thereof which are illustrated in the appended drawings.

It is noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

Fig. 1 is a side view of a floating platform anchored to the seabed by the tendon system of the present invention;

Fig. 2 is a longitudinal section view of a tendon of the present invention depicting a synthetic tendon located within a steel tendon;

Fig. 2A is a section view taken along line 2A-2A of Fig. 2;

Figs. 3 - 6 are top views illustrating single and multi-column platforms incorporating the tendon systems of the present inventions;

Fig. 7 is a side view illustration of a tanker anchored to the seabed by a single anchor leg mooring incorporating the tendon system of the present invention;

Fig. 7A is a section view taken along line 7A - 7A of Fig. 7;

Fig. 8 is a partial side view of a platform incorporating a dry computer controlled damping force system for exerting a damping force to disrupt vertical resonance in the Platform system of the invention;

Fig. 9 is a partial side view of a platform incorporating a wet computer controlled damping force system for exerting a damping force to disrupt vertical resonance in the Platform system of the invention;

Fig. 10 is a partial side view of a platform incorporating an adjustable passive system for exerting a damping force to disrupt vertical resonance in the Platform system of the invention;

Fig. 11 is side view of a platform incorporating passive tuned oscillator devices for exerting a damping force on the platform;

Fig. 11A is a top plan view of the system shown in Fig. 11;

Fig. 12 is a side view of a platform incorporating a driven oscillator damping device for exerting a damping force on the platform; and

Fig. 12A illustrates a block diagram of the driven oscillator damping device shown in Fig. 12.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Referring first to Fig. 1, a single column floating platform generally identified by the reference numeral 10 is shown. The floating platform 10 is anchored to the seabed 12 by the tendon system of the present invention. The floating platform 10 includes a column or hull 14 projecting above the water surface 16. Pontoons 18 extend radially outward from the base of the hull 14.

In a typical tendon design, one or more steel tendons are utilized to secure the floating platform 10 to the seabed 12. As exploration and production of oil reserves expands into deeper waters, the design of the tendon system becomes more critical and begins to dominate the platform costs. The tendon system must be designed to limit the fatigue damage caused by each wave cycle. This is typically accomplished by increasing the cross-sectional area of the steel tendon. But this increases the weight of the tendon and reduces the payload carrying capacity of the platform 10.

Referring still to Fig. 1, the floating platform 10 of the present invention is anchored to the seabed 12 by a composite tendon system including steel tendons 20 and tendons 22 fabricated of synthetic materials arranged in an array or tendon group connected to the distal ends of the pontoons 18 at the upper ends thereof and to the seabed 12 at the lower ends thereof. The tendons 22 comprise high-strength, light-weight synthetic materials, such as carbon fiber composites (CFC), to serve as stiffness members for increasing the vertical stiffness of the tendon group. In a typical mono-column

TLP installation as shown in Fig. 1, two steel tendons 20 and one CFC tendon 22 are connected to the distal ends of the pontoons 18. The steel tendons 20 serve as the primary strength elements while the light-weight CFC tendons 22 provide additional stiffness for limiting the vertical spring of the tendon group. The same principal applies to a conventional multi-column platform. In such designs, multiple steel tendons and one or more CFC tendons attach to the anchoring column or columns of the floating platform as best shown in Figs. 3-6.

Referring now to Figs. 2 and 2A, an alternate embodiment of the present invention contemplates locating a CFC tendon 24 within the steel tendon 20. The CFC tendon 24 is coaxially positioned within the steel tendon 20. In such a configuration, the CFC tendon is protected from the seawater and may integrate other non-strength functions such as fiber optic strands for monitoring tendon condition. The CFC tendon 24 is locked off at the bottom of the steel tendon 20 at a lower internal termination shoulder 21, pre-tensioned and then locked off at the top of the steel tendon 20 at an upper internal termination shoulder 23. A lower connector 25 connects the steel tendons 20 to anchor piles 27 secured in the seabed 12. The upper ends of the steel tendons 20 are connected to the pontoons 18 or columns 31 of the multi-column floating platform 30, shown in Figs. 5 and 6, by a connector 29. The upper end of the tendon 20 is closed off by a plug 33 or the like.

The tendon system of the present invention is likewise applicable to a single anchor leg mooring (SALM) tanker mooring as shown in Fig. 7.

In another aspect of the invention, an active control system is disclosed for avoiding the cost premiums associated with fatigue-driven tendon design. The active control system disrupts resonance motions in the tendon system by applying a varying damping force on the platform system.

One means to accomplish resonance disruption is to exert a damping force on the tendon system by means of a computer controlled damping force system, such as a winch or hydraulic system, that acts on an element connecting the damping force system to the seabed. Referring now to Figs 8 and 9, such connection means may comprise steel cable, synthetic cable, synthetic tendon, or steel tendon identified by the reference numeral 36 and anchored to the seabed 12 at 37. One such active connection means is located on each pontoon 18. The damping force system 38 may be mounted above the waterline 16 with a system of sheaves 40 directing the cable 36 to the seabed 12 shown in Fig. 8. Alternatively, an underwater damping force system 42, as shown in Fig. 9, may be installed on the pontoon 18 to more directly develop a damping force in the cable means 36. Power and control is provided to the damping force system 42 through an electrical or hydraulic line 39 connecting the damping force system 42 to a power source.

A damping force may also be developed in the cable means 36 by mounting a passive spring and dashpot 41 to the distal ends of the pontoons 18 as depicted in Fig. 10.

Another means of counteracting expected or unexpected vibrations in a platform system is to provide damping forces through a passive tuned resonant oscillator or actively driven oscillating mass system. The tuned oscillator system is similar in function to such systems used to prevent swaying of tall building structures, but is composed of water mass and air chamber spring. One possible configuration is shown in Fig. 11. The water mass 50 oscillates vertically against an air spring 51 within an open bottomed chamber 52. One or more vertical chambers 52 are mounted about the exterior surface of the hull 14 of the platform 10 as shown in Fig. 11A.

In an alternate embodiment shown in Fig. 12, a similar water mass system driven by an active forcing system is shown. In the active forcing system, the water mass 56 is driven by air pressure 55,

all contained withing an open bottomed chamber 57. The controlled forcing is provided by a computer control system 60 and air supply 58.

While a preferred embodiment of the invention has been shown and described, other and further embodiments of the invention may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims which follow.